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DEVELOPMENT OF A LITHOSPHERIC MODEL AND GEOPHYSICAL DATA BASE FOR NORTH AFRICA

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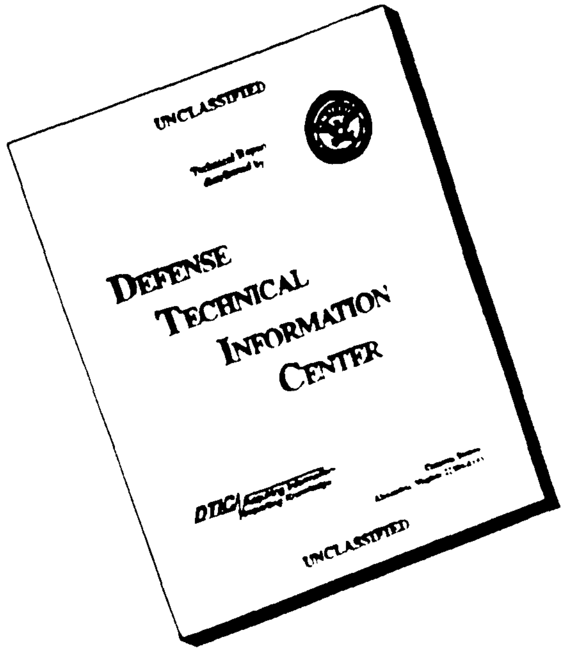

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13. ABSTRACT *(Maximum 200 words)*
We have collected seismic, geologic, gravity and other potential field data to develop a model of the North Arican lithosphere via an integrated approach. We have constructed a gravity data base for the region, including over 5300 gravity readings for northern Libya. We have generated a Bouguer gravity map of northern Africa and are currently modeling gravity data along three transects across North Africa. These results were used as the basis on which to construct a preliminary map of crustal thickness for the region. The maps and interpreted transects are available through a World Wide Web site, and the gravity data base can also be accessed electronically. We have begun a collection of seismograms from Worldwide Standardized Seismograph Netowrk stations located at regional distances from magnitude greater than 5.0 earthquakes occurring within North Africa (between 1963 and 1988) and their associated aftershocks. We have collected delay time, travel time, focal mechanisms, focal depth and magnitude information for these sequences for further analysis. At present, these data are being compiled into a database available on floppy diskette, but will eventually be transferred to a World Wide Web site.

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Summary

We have collected seismic, geologic, gravity and potential field data to develop a model of the North African lithosphere via an integrated approach. We are currently modeling the gravity data along three transects across North Africa: 1) from north central Egypt across Libya to the Hoggar Uplift, 2) from central Tunisia across northern Algeria to the Atlantic coast of Morocco, 3) from north central Algeria across the Hoggar Uplift to northern Chad. These transects represent the major propagation paths between earthquakes and nuclear explosions and seismograph stations located within North Africa. The gravity models are constrained wherever possible by geologic and other geophysical information. Crustal thicknesses we have obtained for the Hoggar Uplift (38 km) agree well with preliminary results of seismological studies by other research groups. Our modeling results also suggest that the mantle anomaly under the Hoggar Uplift is relatively small (200-300 km wide, less than 60 km in vertical extent) compared to mantle anomalies associated with other hot spots and rift zones.

We have used our modeling results in conjunction with other geophysical studies to construct a preliminary map of crustal thickness for Africa. In most places away from the continental margin, the crust in North Africa is 35-40 km thick. Crustal thinning is associated with the Sirt Basin and the West and Central African rift system. Moderate crustal thickening is associated with the Atlas Mountains.

In addition to our gravity studies, we have been compiling a collection of seismograms from Worldwide Standardized Seismograph Network (WWSSN) stations located at regional distances for magnitude ≥ 5.0 earthquakes occurring within North Africa (between 1963 and 1988) and their associated aftershocks. We have selected these earthquake sequences for study since many of the mainshocks have known focal mechanisms determined from teleseismic waveform modeling or first motion studies of regional, teleseismic and/or local network data. Many of the events produced numerous aftershocks of varying magnitudes. Using the lithospheric models obtained from the gravity modeling as first approximations of the velocity structure, we will model the regional waveforms of these earthquake sequences. We have also collected delay time, travel time, source parameter and magnitude information for these sequences for further analysis.

Introduction

North Africa has been the object of considerable oil exploration and a fair number of papers containing geological interpretations of upper crustal structure have been published. However, very few papers contain basic data which are relevant on the scale of a lithospheric investigation. Our task has been to develop a model of North African lithosphere via an integrated analysis of seismic, potential field, and geologic data. In particular, we have concentrated on constructing detailed 2-D models from known earthquake source regions to key seismic monitoring stations in the region. An outgrowth of this effort is a data base of geological and geophysical information which will be made available to the scientific community through electronic access.

Although data are sparse in many regions, it is clear that North Africa has experienced a complex evolution (Figure 1). The structure of the lithosphere presently must bear the signature of these tectonic events, and seismic waves propagating through it must be affected. The Pan-African orogeny (750-500 Ma) may represent the time at which the shield areas formed by terrane accretion (Black et al. 1994). This could be similar to the formation of the China region in the Paleozoic and Mesozoic. During the Paleozoic, the Caledonian and Hercynian orogenies affected the region and formed a series of basins and uplifts in a manner similar to the evolution of the midcontinent region of the U.S. during this same period. In the Cretaceous, Africa was subjected to widespread rifting and nearly split apart (Fairhead, 1992). During the Tertiary, the Alpine orogeny affected North Africa, most notably forming the Atlas Mountains. Volcanic centers such as Hoggar and Tibesti formed on topographic uplifts which are believed to related to mantle plumes (Figure 1).

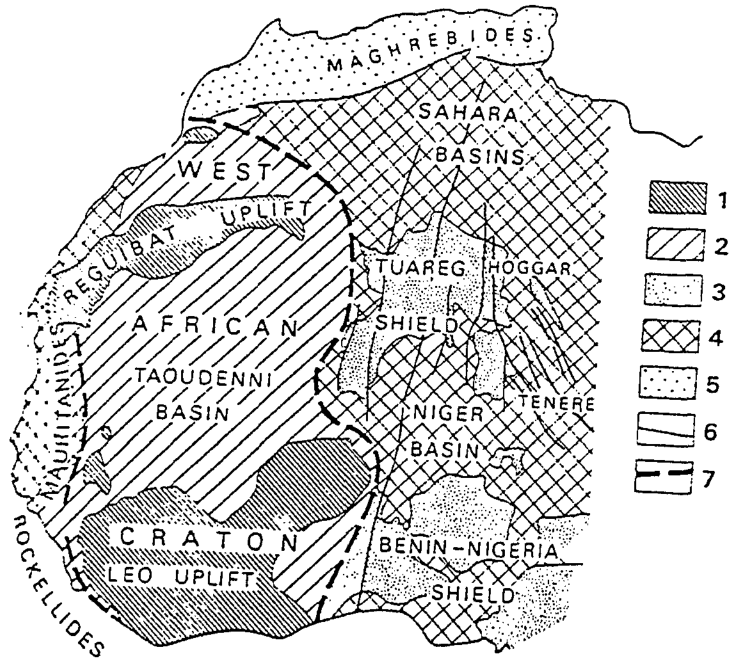
Our approach to constructing a lithospheric model and data base for North Africa has been to integrate information such as well logs, gravity measurements, aeromagnetic surveys, heat flow measurements, and geologic maps to first develop lithospheric models along key profiles in North Africa. We then will use these models as a starting point for modeling seismograms at regional distances, refining the models as the seismic data require. In following subsections we describe our data collection process. We then discuss the results of our gravity modeling and analysis. The appendices describe the data bases we have collected and how they can be accessed electronically.

Methods, Assumptions and Procedures

Geological Data Base

We have digitized the locations of numerous geological features within the North African region to aid in our interpretation of gravity and seismic data. These features include: surface exposures of Precambrian rocks in the major uplifts, depth to Paleozoic and Mesozoic basement within the Sirt Basin of Libya, surface faults within the Sirt Basin, the location of Pan-African suture zones and Cretaceous and Cenozoic age rifts, and the boundaries of West and Central African rift basins. Maps of these features are shown in Appendix A, along with details on how these outlines can be accessed electronically.

A



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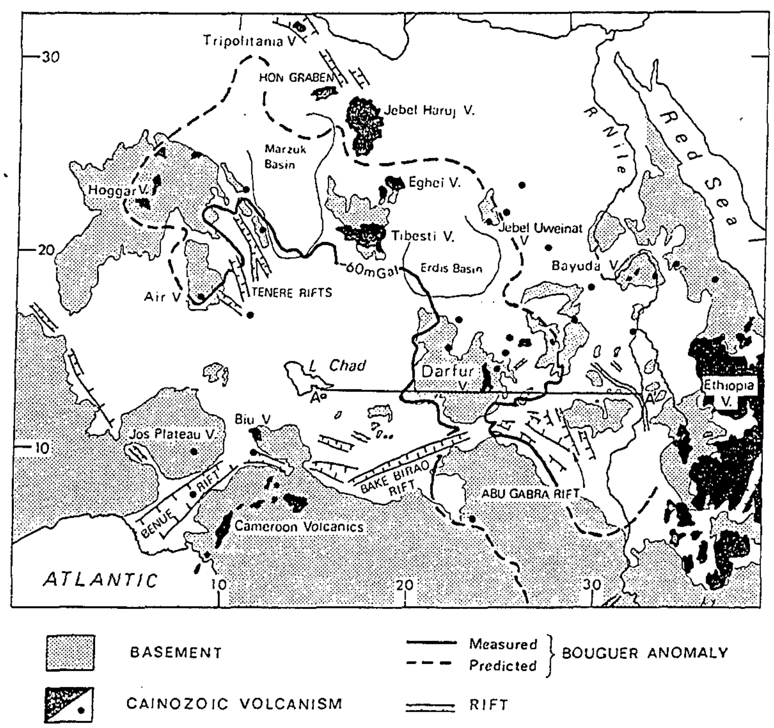

Figure 1. Generalized tectonic maps of northern Africa A-northwest; B-northeast

Gravity Data Base

We have collected gravity data from a number of sources. First we began with the unclassified data from the global data base maintained by the Defense Mapping Agency. For these data, we have complete information including elevation and there are over 36,000 data points. To this we have added data from Libya which were compiled by one of our graduate students (Suleiman, 1993). These data (over 5000 points) come from a variety of industrial sources, and thus, complete information is lacking. We do have latitude, longitude, and Bouguer anomaly value (density - 2.67 gm/cc). Details concerning these data are available in Appendix B.

A third and very important set of data was obtained in the form of a 5'x5' Bouguer gravity anomaly grid from GETECH, which is associated with Leeds University. These data are for the region between 0° and 37°N and 12°W and 40°E. We are only free to use these data in the form of maps which are contoured at intervals of 10 mGal or greater. Gravity station locations were also provided so that we can clearly see the constraints that these data provide. In addition, the station elevations were used by GETECH to correct errors in the ETOPO5 topographic data base, and we are using this commercial product in our study. The ETOPO 5 data base is available from the National Geophysical Data Center, and the corrected data are directly available from GETECH.

All three data sets have been merged to produce the Bouguer gravity map of Northern Africa (Figure 2). Details on the availability of these data can be found in Appendix B.

Seismic Data Base

We have selected a series of magnitude ≥ 5.0 earthquakes and their associated aftershocks occurring between 1963 and 1988 (the major years of operation of the WWSSN) for study (Figure 3, Table 1). Many of the mainshocks have focal mechanisms determined from teleseismic waveform modeling or first motion studies (Table 2). Some sequences produced numerous aftershocks, and we are collecting data for all events above magnitude 3.5. The data we are collecting consist of: 1) location, origin time, arrival time, delay time, magnitude, and first motion information from listings of the International Seismological Centre or the U.S. Geological Survey's Earthquake Data Report, 2) published focal mechanisms, focal depth and other source parameter information determined from teleseismic or local network information, and 3) waveform data copied from microfiche for WWSSN stations located at regional distances from the events of interest.

We have collected about 75% of the listing information and have entered much of the information into a PC based version of the EXCEL spreadsheet/data base software. Examples of spreadsheets and other details related to this information are given in Appendix C. Figure 4 shows an example of how we plan to compare P-wave delay times versus azimuth for events within different regions of North Africa. This plot shows the delays for a magnitude 4.5 aftershock of the 1969 northern Red Sea earthquake sequence.

We have conducted a fairly extensive search of the literature for focal mechanism information and believe we have collected about 90% of the available focal mechanisms. We hope to determine focal mechanisms for other M≥ 5.0 events from first motion

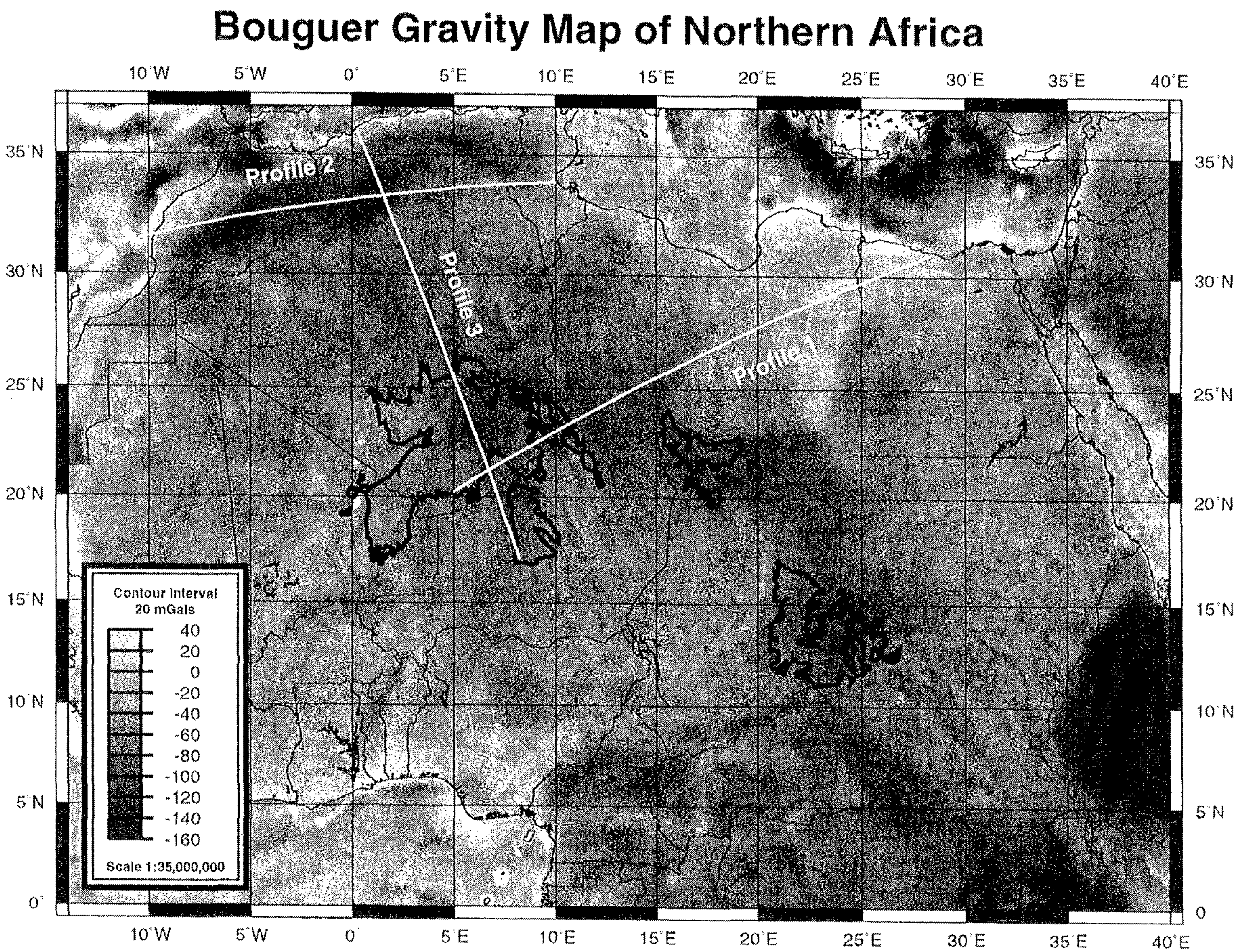

Figure 2. Preliminary Bouguer gravity map of North Africa. Contour interval: 20 mgal. Precambrian outline of Ahaggar (Algeria), Tibesti (S. Lybia), and Darfur (E. Chad and W. Sudan) domal uplifts shown in dark black. Locations of three crustal-scale gravity profiles also shown in white.

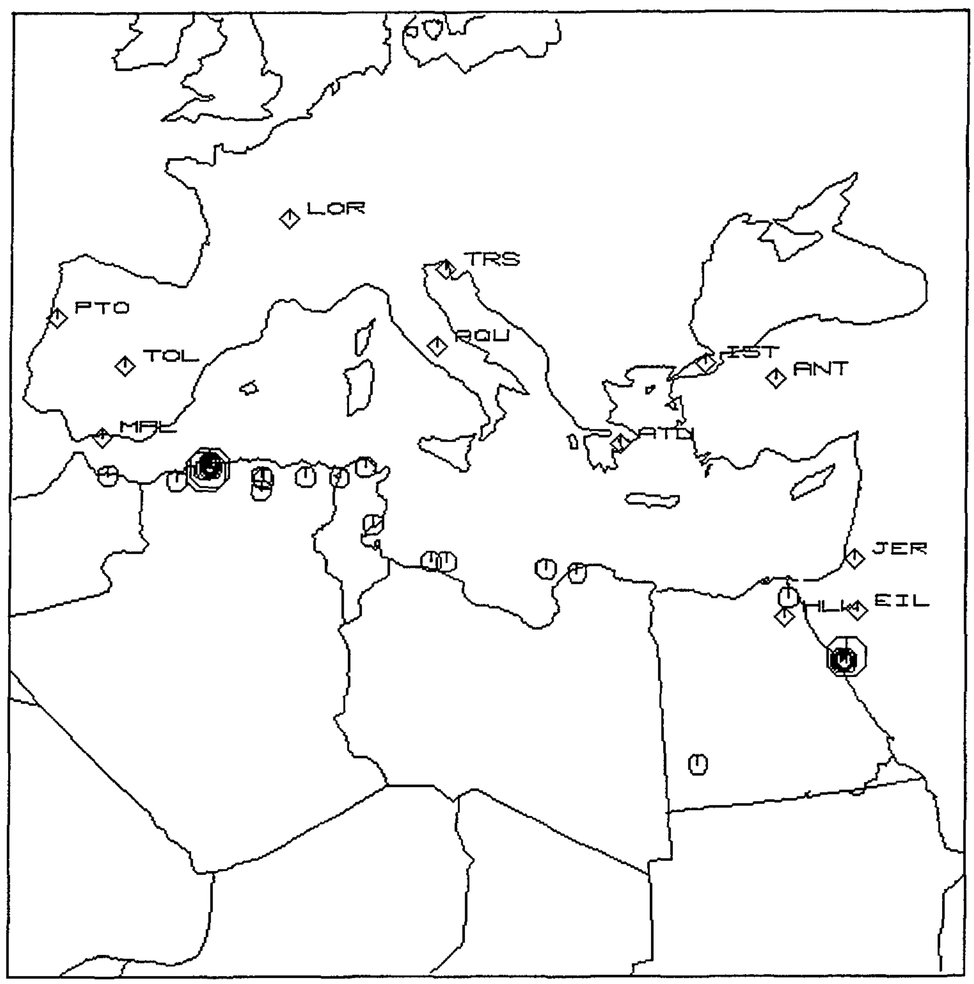

Figure 3. Magnitude ≥ 5.0 earthquakes of North Africa (1963-1988). Large circles are magnitude ≥ 6.0 earthquakes. Labeled diamonds represent locations of WWSSN stations operating during the period of interest.

Table 1. Magnitude ≥ 5.0 Earthquakes (1963-1988) in North Africa of Interest to This Study

Date	Time	Magnitude	Location
Feb. 21, 1963	1724	5.0	Gulf of Sidra
May 11, 1963	0110	5.8	Gulf of Sidra
Jan. 1, 1965	2138	5.0	M'Sila, Algeria
Jan. 26, 1967	1611	5.1	Tunisia
July 13, 1967	0210:	5.0	Algeria
Apr. 17, 1968	0912	5.1	Boudinar, Morocco
Mar. 24, 1969	1154	5.2	N. Red Sea, Egypt
Mar. 31, 1969	0715	6.0	N. Red Sea, Egypt
Mar. 31, 1969	2142	5.0	N. Red Sea, Egypt
Apr. 8, 1969	1031	5.2	N. Red Sea, Egypt
Apr. 16, 1969	0812	5.0	N. Red Sea, Egypt
Apr. 23, 1969	1337	5.0	N. Red Sea, Egypt
Dec. 1, 1970	0102	5.2	Tunisia
Jan. 12, 1970	0815	5.1	N. Red Sea, Egypt
Sept. 2, 1972	1453	5.3	Gulf of Sidra
June 28, 1972	0949	5.5	N. Red Sea, Egypt
Nov. 24, 1973	1405	5.1	Algeria
Nov. 24, 1973	1522	5.3	Algeria
April 29, 1974	2004	5.0	Nile Delta, Egypt
Sept. 4, 1974	0629	5.5	Tripoli, Libya
Jan. 1, 1977	2046	5.7	A'in Soltane, Tunisia
Dec. 9, 1978	0713	5.3	W. Egypt
Oct. 10, 1980	1539	6.1	El Asnam, Algeria
Oct. 10, 1980	1733	5.2	El Asnam, Algeria
Oct. 10, 1980	1908	5.0	El Asnam, Algeria
Oct. 13, 1980	0637	5.0	El Asnam, Algeria
Oct. 14, 1980	1734	5.0	El Asnam, Algeria
Oct. 30, 1980	2338	5.1	El Asnam, Algeria
Nov. 8, 1980	0754	5.1	El Asnam, Algeria
Dec. 12, 1980	1332	4.8	El Asnam, Algeria
Dec. 7, 1980	1737	5.1	El Asnam, Algeria
Jan. 15, 1981	0425	5.1	El Asnam, Algeria
Feb. 1, 1981	1320	5.2	El Asnam, Algeria
Oct. 27, 1985	1934	5.7	Constantine, Algeria

Table 2. Focal Mechanisms for M≥5.0 North African Earthquakes (1963-1988)

Date	Mechanism strike,dip,rake	Data Used	Reference
Feb. 21, 1963	243,75,90	first motion	McKenzie (1972)
Jan. 1, 1965	70,65,68	first motion	McKenzie (1972)
July 13, 1967	167,30,90	first motion	McKenzie (1972)
Mar. 31, 1969	330,50,5	waveforms	Ben-Menahem et al. (1976)
	325,50,-40	first motion	McKenzie et al. (1970)
Jan. 12, 1972	8,86,-10	waveforms	Pearce (1980)
June 28, 1972	350,80,10	waveforms	Pearce (1977)
Apr. 29, 1974	310,47,-17	waveforms	Ben-Menahem et al. (1976)
Sept. 4, 1974	297,37,-141	waveforms	Westaway (1990)
Oct. 10, 1980	225,54,83	waveforms	Deschamps et al. (1982)
Oct. 30, 1980	42,40,72	first motion	Yielding et al. (1989)
Nov. 8, 1980	41,64,75	first motion	Yielding et al. (1989)
	50,30,97	first motion	Ouyed et al. (1983)

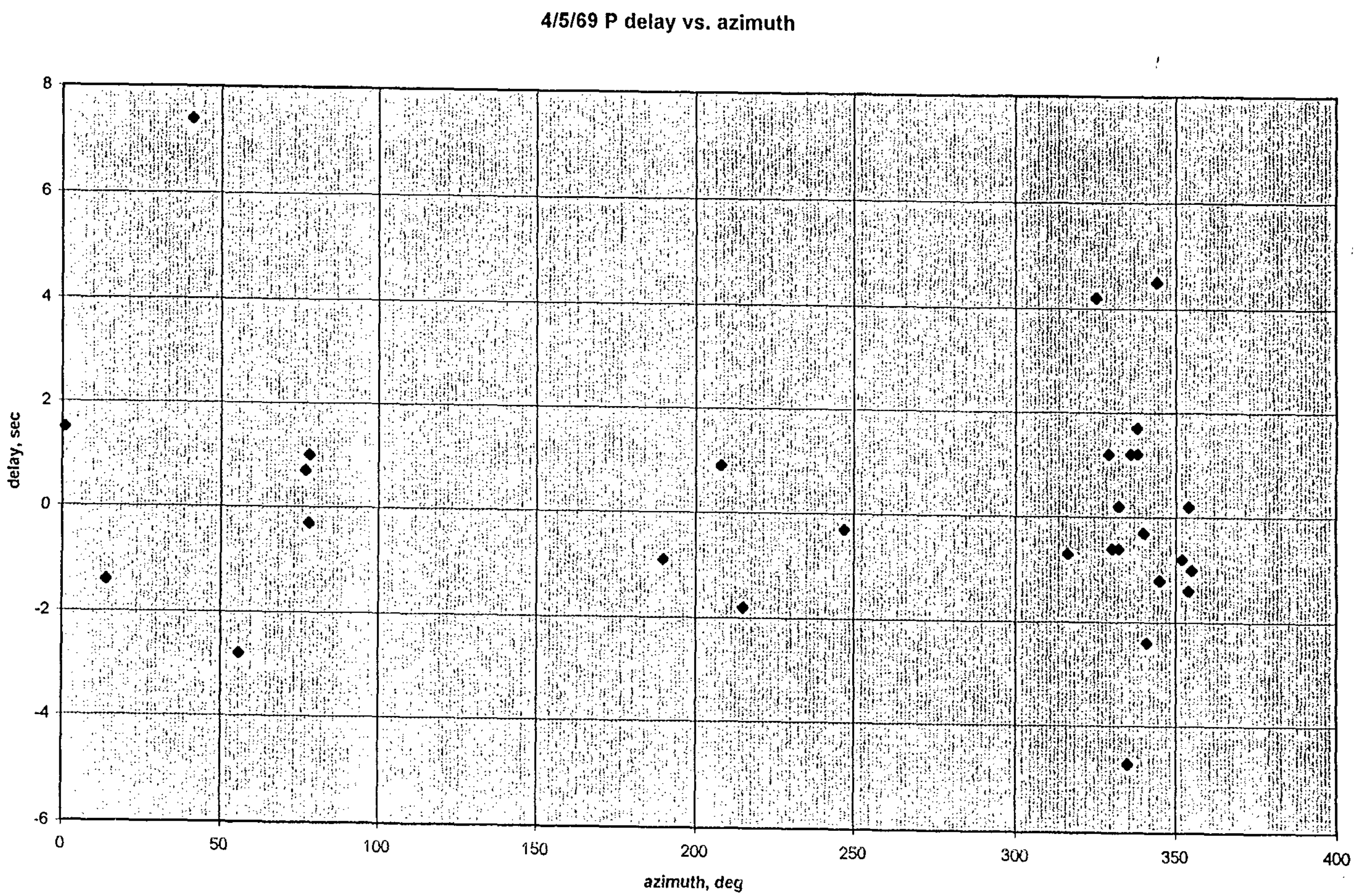

Figure 4. Plot of P-delay (observed minus predicted arrival time from listings of the International Seismological Centre) versus azimuth from event to station for an aftershock of the 1969 northern Red Sea earthquake sequence.

information we have collected using the grid search program of Whitcomb (1973) to determine a best fit focal mechanism.

About 50% of the regional waveform data have been collected, and we have just begun to digitize these seismograms. Figure 5 shows an example of an M=5.0 aftershock of the October 1980 El Asnam sequence recorded at Toledo, Spain (TOL) located at 625 from the event. During the second year of the research we will model these waveforms to validate and update the preliminary lithospheric models obtained from the gravity data. We will employ reflectivity (Randall and Taylor, written comm., 1993) and full waveform finite difference (Sandmeier, 1990) in this modeling process.

Results and Discussion

Gravity Modeling

Once we had merged the GETECH data into our existing database, we selected three profiles across the region to model (Figure 2). These profiles represent important propagation paths between earthquakes and seismograph stations located within North Africa. Profile 1 extends from central Egypt, the site of several recent earthquakes and seismograph stations (such as HLW), across central Libya, where we have good geological and geophysical control on crustal structure (e.g. Suleiman, 1993; Nyblade et al., 1996), to the Hoggar Uplift of southern Algeria (site of station TAM, Tamanrasset, and several French nuclear tests in the early 1960's). Profile 2 extends across the Atlas Mountains from the Atlantic coast of Morocco to central Tunisia. Seismograph stations are located along this profile in Morocco, Algeria and Tunisia, and earthquakes occur throughout the region. Profile 3 extends from north central Algeria across the Atlas Mountains to the Hoggar uplift. This profile is along the propagation path between northern Algerian earthquakes and TAM. A preliminary velocity model has been obtained by McNamara et al. (1996) from regional seismograms whose waves propagate along paths that parallel Profile 3.

The preliminary density model we have obtained for Profile 1 is shown in Figure 6. The upper part of our model reflects the basin structure of Egypt, Libya and Algeria obtained from published geological and geophysical studies of these basins (e.g. Goudarzi, 1980; van der Meer and Cloetingh, 1993; Guirard and Maurin, 1992; Exxon, 1985), primarily related to their petroleum potential. Since our knowledge of the upper crust below the sedimentary basins and the lower crust is poor, we have treated these units as having uniform densities. We varied thicknesses of these units only as required to match the long wavelength features of the observed gravity data. Note that we have not attempted to match every short wavelength feature of the profile, since our knowledge of the shallow geology is incomplete. The shallow geology also should influence regional waveform propagation less than the deeper crustal structure.

Profile 1 shows a relatively uniform boundary between the upper and lower crust. There is a gradual shallowing of the crust/mantle boundary between the Hoggar Uplift (38 km) and the Egyptian coast of the Mediterranean (26 km) (Sweeney, 1995). A similar eastward shallowing of the crust/mantle boundary is observed in northern Libya (Suleiman, 1993). The crustal thickness of the Hoggar Uplift is in good agreement with the velocity model of McNamara et al. (1996) and recent receiver function studies at TAM (E. Sandoval, pers. comm., 1996).

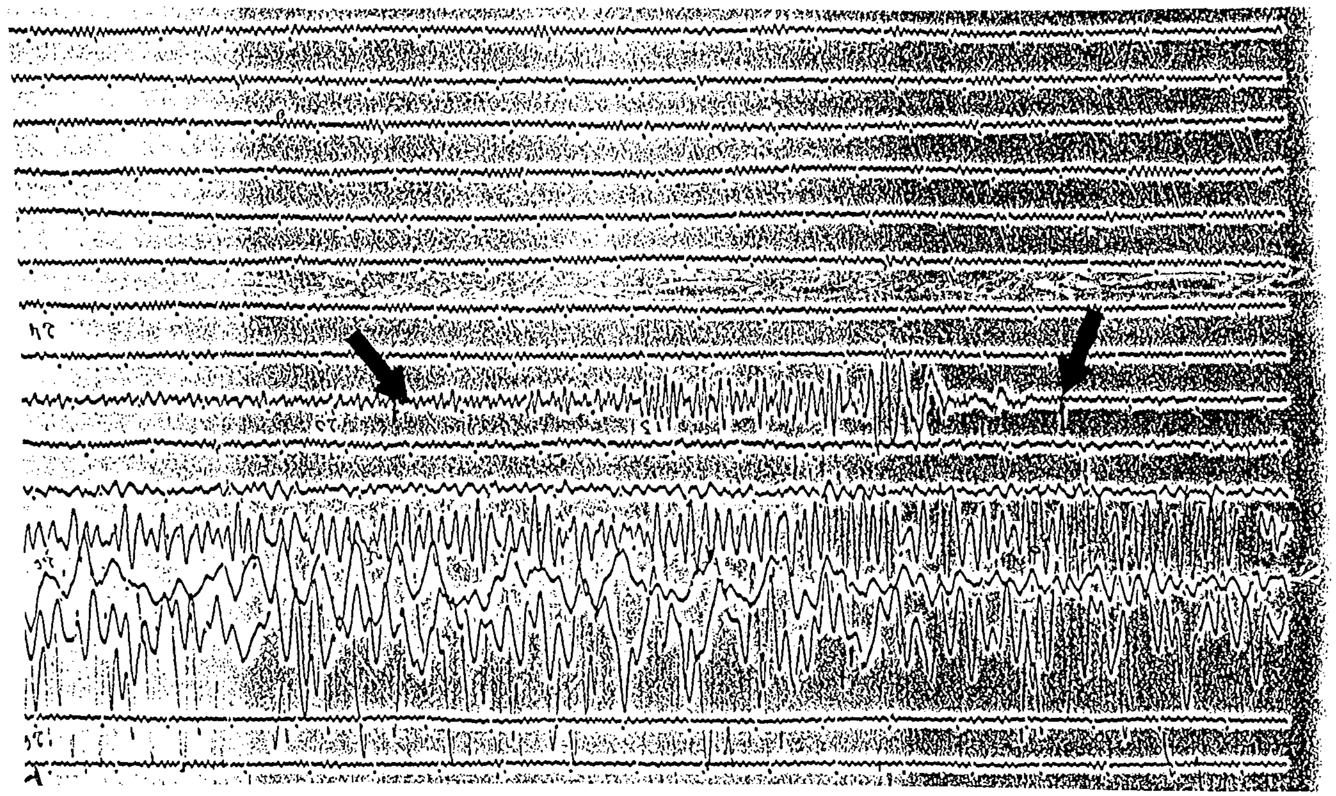

Figure 5. Seismogram of magnitude 5.0 aftershock of the October 1980 El Asnam, Algeria, earthquake sequence. Seismogram was recorded on the long-period vertical instrument operating at Toledo, Spain (TOL).

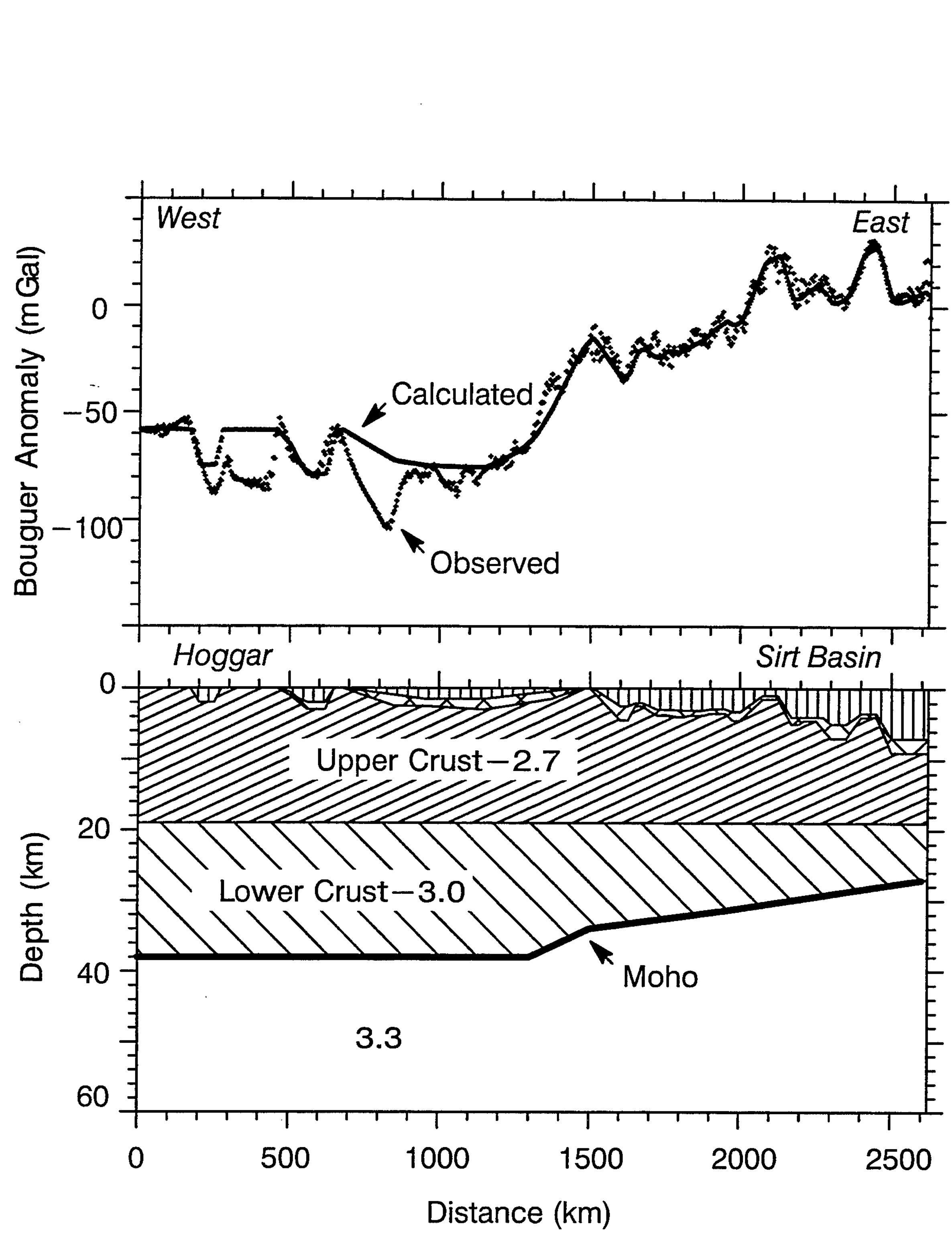

Figure 6. Preliminary interpretation of gravity data along Profile 1 trending West-East from Ahaggar domal uplift (Algeria) to Mediterranean coastline (Egypt) (total length=2620 km). Above: Observed and calculated gravity values for each station along profile. Below: Crustal model used to generate calculated gravity values. Moho discontinuity shown in bold. Numbers are densities for the bodies (g/cm^3).

Figure 7 shows a preliminary interpretation of Profile 3. The shallow upper crustal structure is constrained from knowledge of basin geometries and thicknesses (e.g. Schurmann, 1974; UNESCO, 1971; Lesquer et al., 1988). The Moho depth at the northern end of the profile is constrained by the results of the European Geotraverse (Ansorge et al., 1992). The crust appears to rapidly thicken beneath the Atlas Mountains, then gradually thicken to the south. Again, the Hoggar Uplift can be modeled with a 38 km thick crust. A gravity low over the uplift suggests the presence of an upper mantle anomaly with width of 200 to 300 km and depth of 40 to 60 km. This is much smaller than observed under the Ethiopian and Kenya domes.

Crustal Thickness Map

Figure 8 shows a preliminary map of crustal thickness based on an integrated analysis of the limited seismic constraints and Bouguer gravity data. Note that the crust is generally 35-40 km thick away from the continental margins. There is a moderate amount of crustal thickening associated with the Atlas Mountains. Crustal thinning is associated with the Sirt Basin and the West and Central African rift system and the adjecent Cameroon line. The lack of a major crustal anomaly associated with the domal uplifts such as the Hoggar is suprising, and we will be investigating this and updating the contour map as our study progresses.

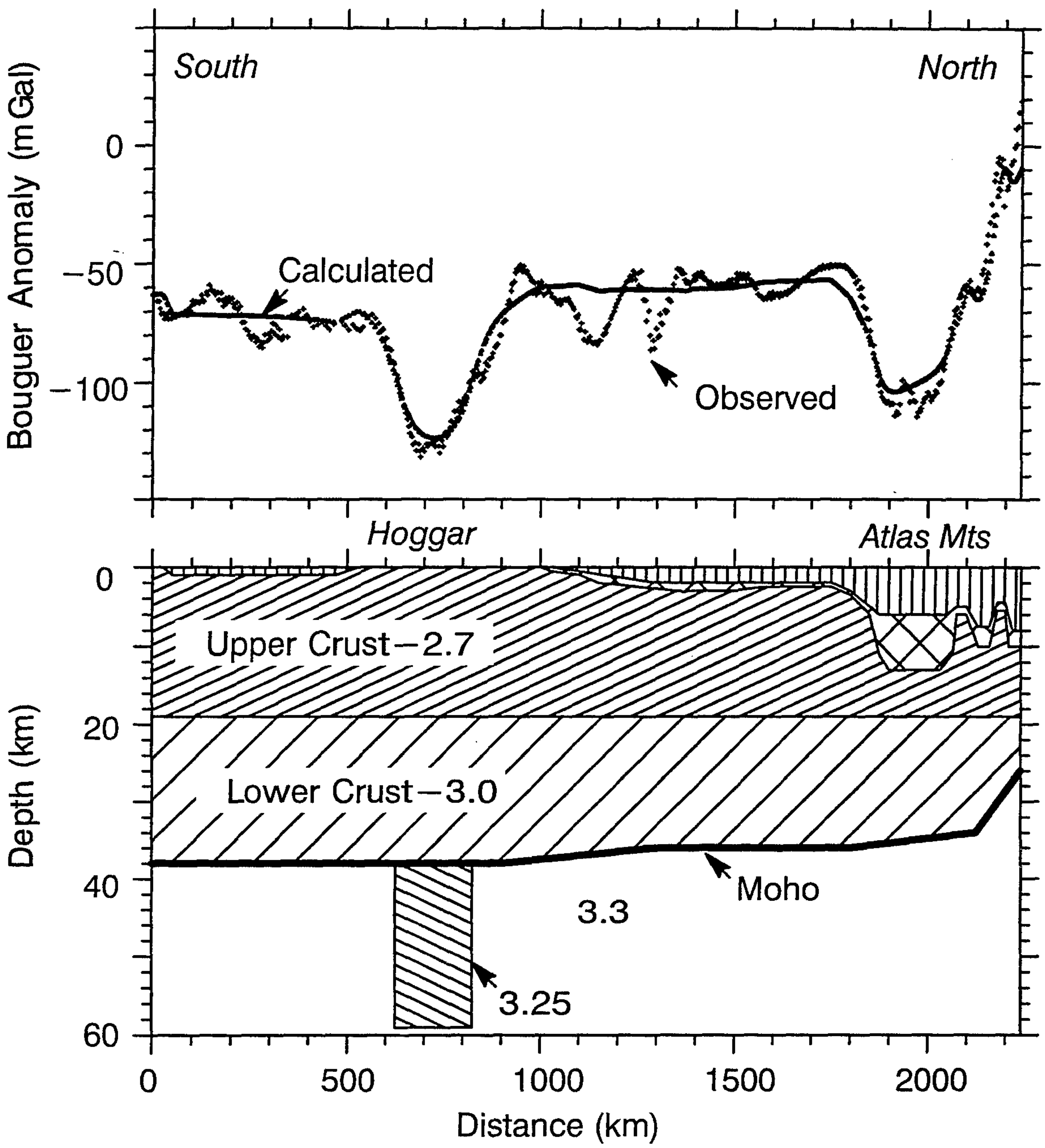

Figure 7. Preliminary interpretation of gravity data along Profile 3 trending South-North from Air massif (Niger) to Mediterranean coastline (Algeria) (total length=2240 km). Above: as in Figure 6. Below: as in Figure 6, with body of density 3.25 g/cm^3 representing possible mantle upwelling.

Figure 8. Preliminary crustal thickness map for Africa. Contour interval - 5 km.

Conclusions

We are continuing our modeling of gravity Profile 2 along the axis of the Atlas Mountains. Further 2-D filtering and analysis of the gravity data set is also planned. Modeling of regional seismic phases will continue throughout the next year. We will analyze the variations in travel times and magnitude estimates for the earthquake sequences of interest. Our final results will be a geophysical and geological data base for North Africa that will be easily accessible to the scientific community and a series of "best" lithospheric models for regions of North Africa that have been validated through waveform modeling of regional seismic phases.

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Appendix A - Documentation of Geological Data Base

The following pages show maps of North African geological features that we have digitized. The data are available at the UTEP Department of Geological Sciences web site under North Africa Project. The sources of data used for the maps we have generated are given below, along with information on the scales of the original maps.

Figure 2 shows the outlines of exposed Precambrian rocks in the Hoggar, Tibesti and Darfur uplifts (heavy, dark lines). These exposures were taken from UNESCO (1986) (1:5,000,000).

Two sets of data are shown in Figure A1. The white lines in the south and northeastern portions of the study area represent Early Cretaceous basins and faults taken from Guirard and Maurin (1992) (~1:55,000,000). White contours in northern Tunisia show a Moho contour map from Research Group for Lithospheric Structure in Tunisia (1992) (~1:600,000).

Rift basins in Niger, Chad and the central African Republic are shown by white lines in Figure A2. They have been digitized from Genik (1992) (~1:2,500,000). Basement faults in north-central Libya are from van der Meer and Cloetingh (1993).

Figure A3 shows structural features of central Libya from Goudarzi (1980) (~1:1,500,000). Structure in Algeria and Chad is from Dautria and Lesquer (1989) (1:10,500,000).

Locations and thickness of Early Cretaceous basins in the northeastern portion of North Africa is shown on Figure A4. These data are from Van Houten (1983) (~1:1,500,000).

Contour map at base of Mesozoic rocks in Libya (Goudarzi, 1980; ~1:1,500,000) is shown in Figure A5. Major geotectonic units of West Africa (Lesquer et al., 1990) are also shown.

A structural contour map of the top of the Precambrian basement in Libya (Goudarzi, 1980; ~1,500,000) is shown in Figure A6. Lines in western portion of North Africa are structures shown in Kirton and Bourennani (1984) (~1:3,000,000).

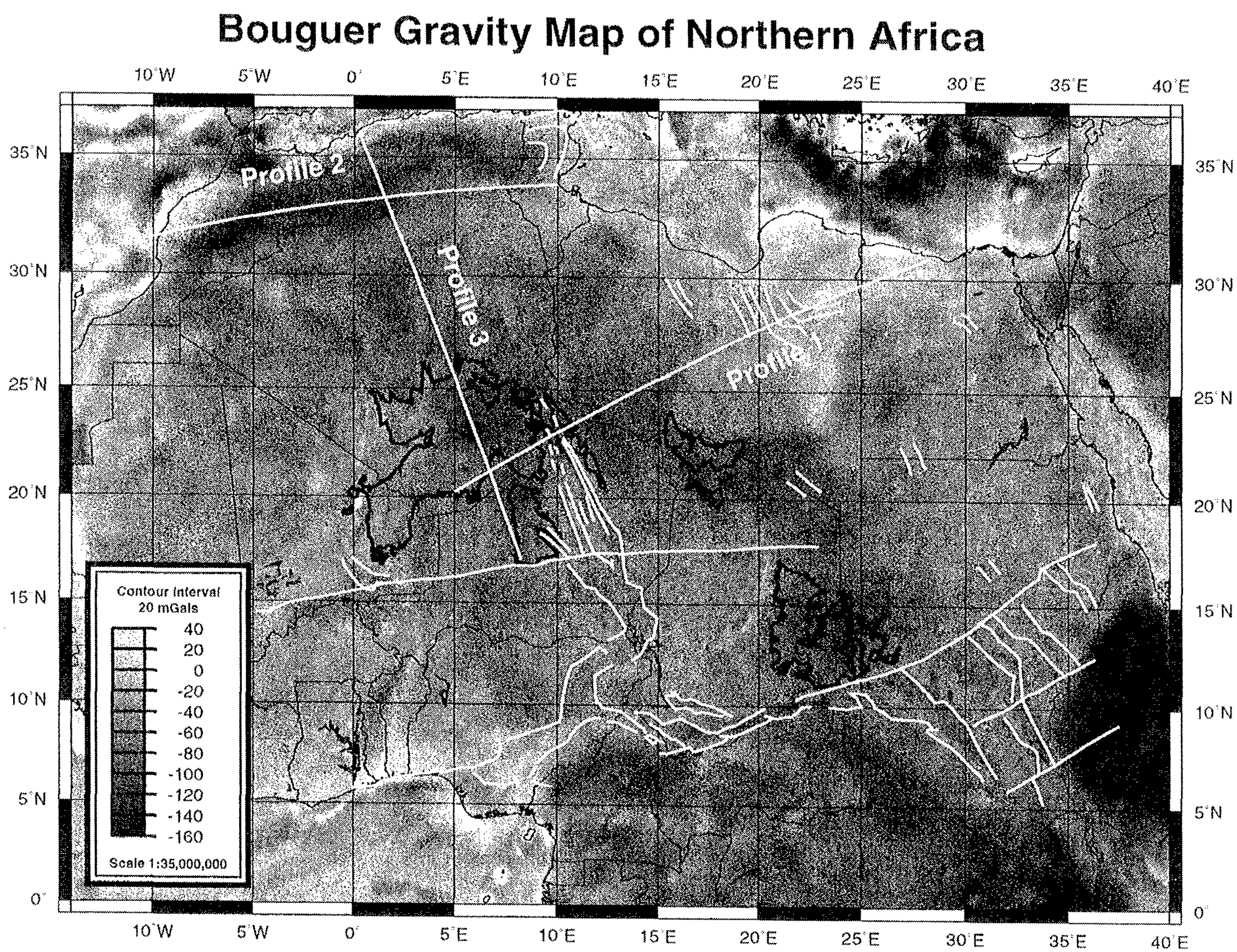

Figure A1. Cretaceous basins and faults, Moho contours for Tunisia

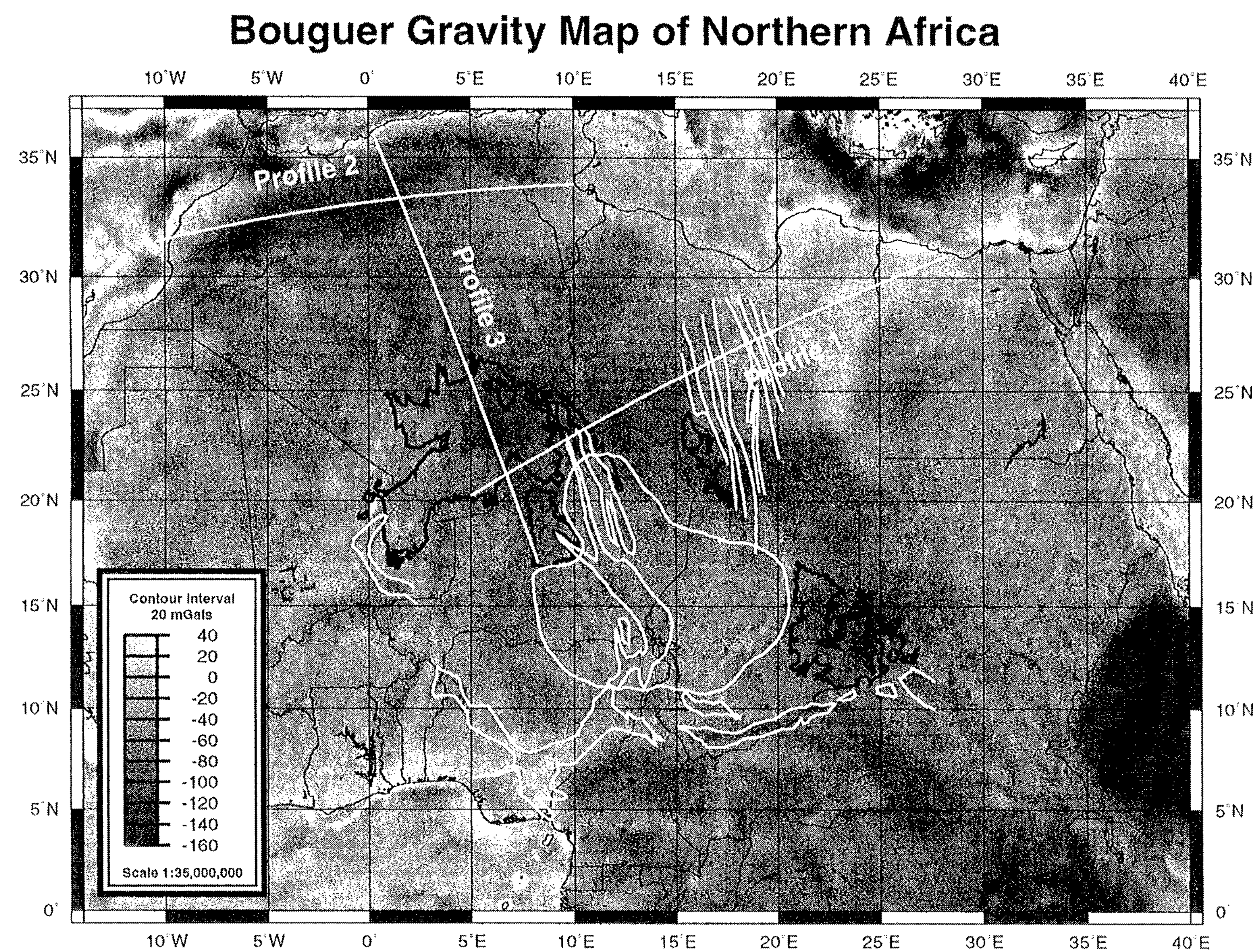

Figure A2. Rifts of southern study area, structure of Libya

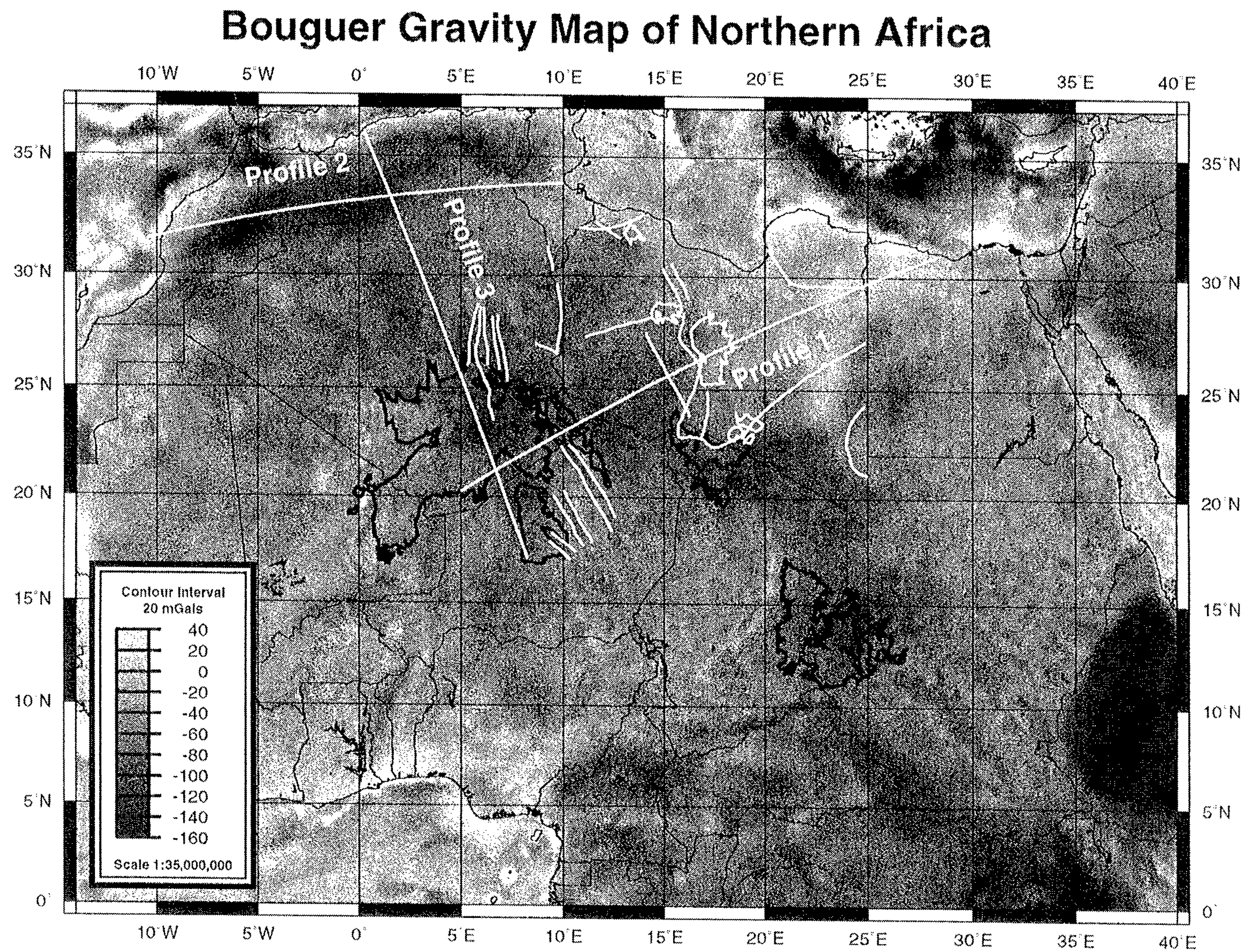

Figure A3. Structure of central Libya, structure of Hoggar uplift

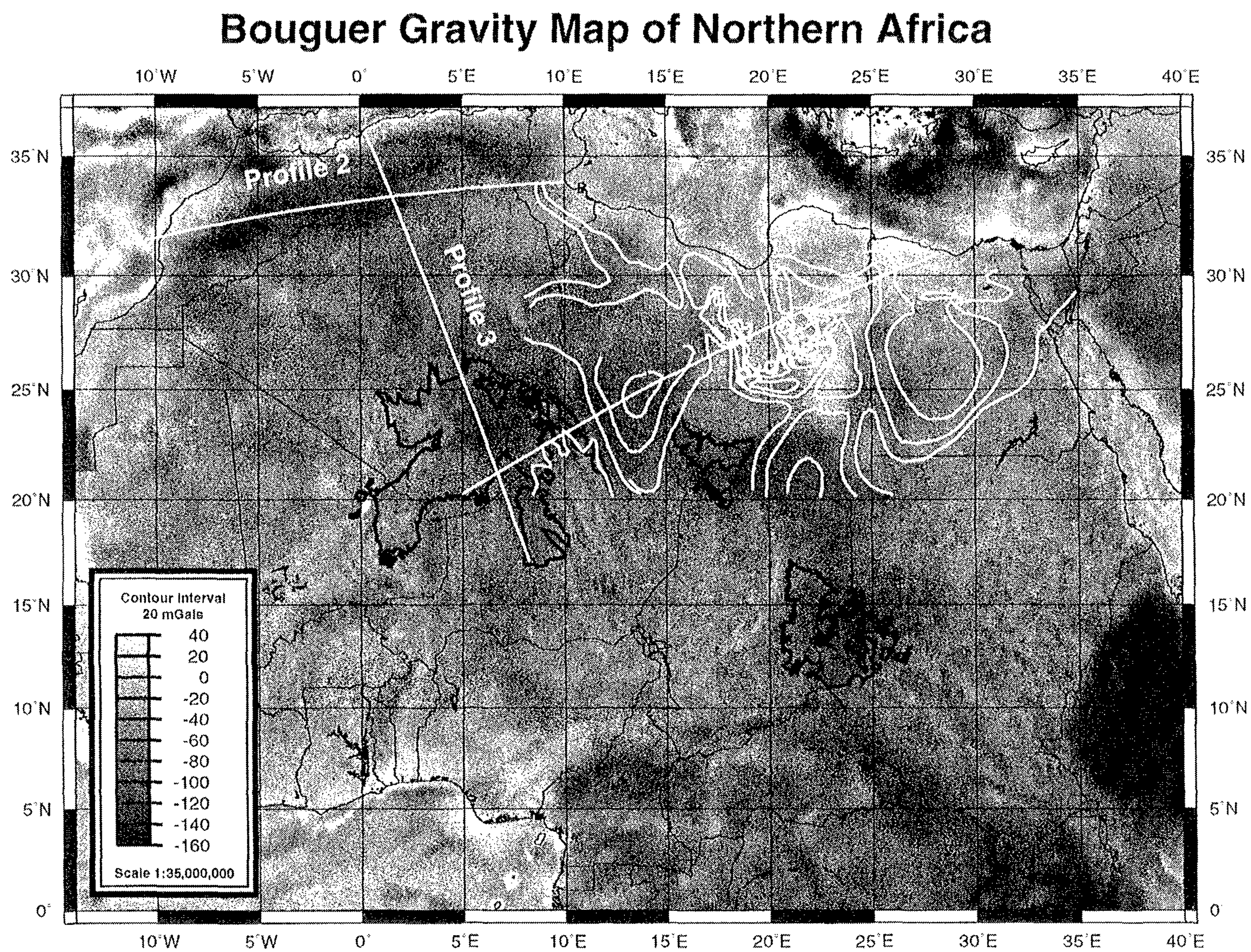

Figure A4. Cretaceous basins of northeastern study area

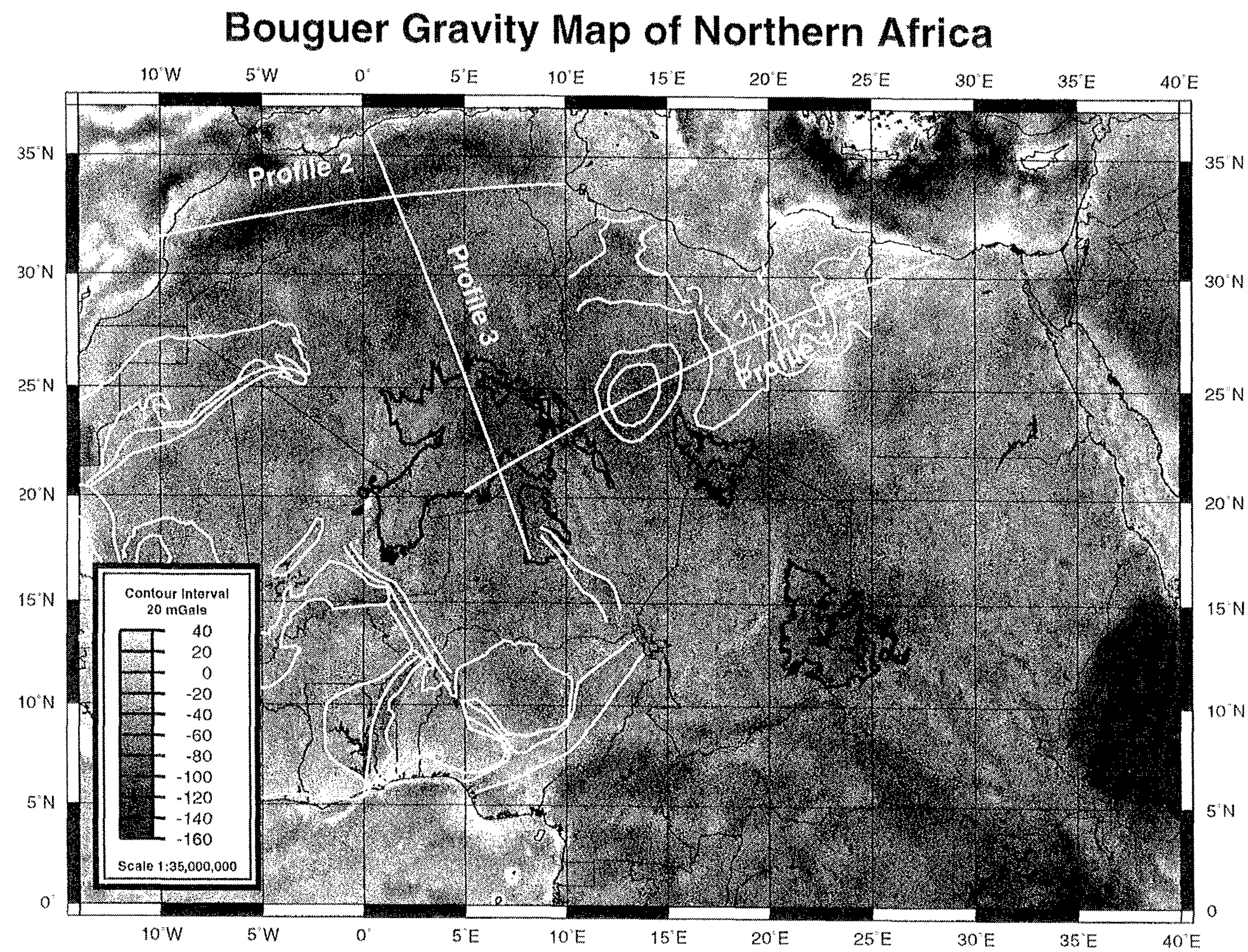

Figure A5. Structure of Mesozoic in Libya, tectonic features of West Africa

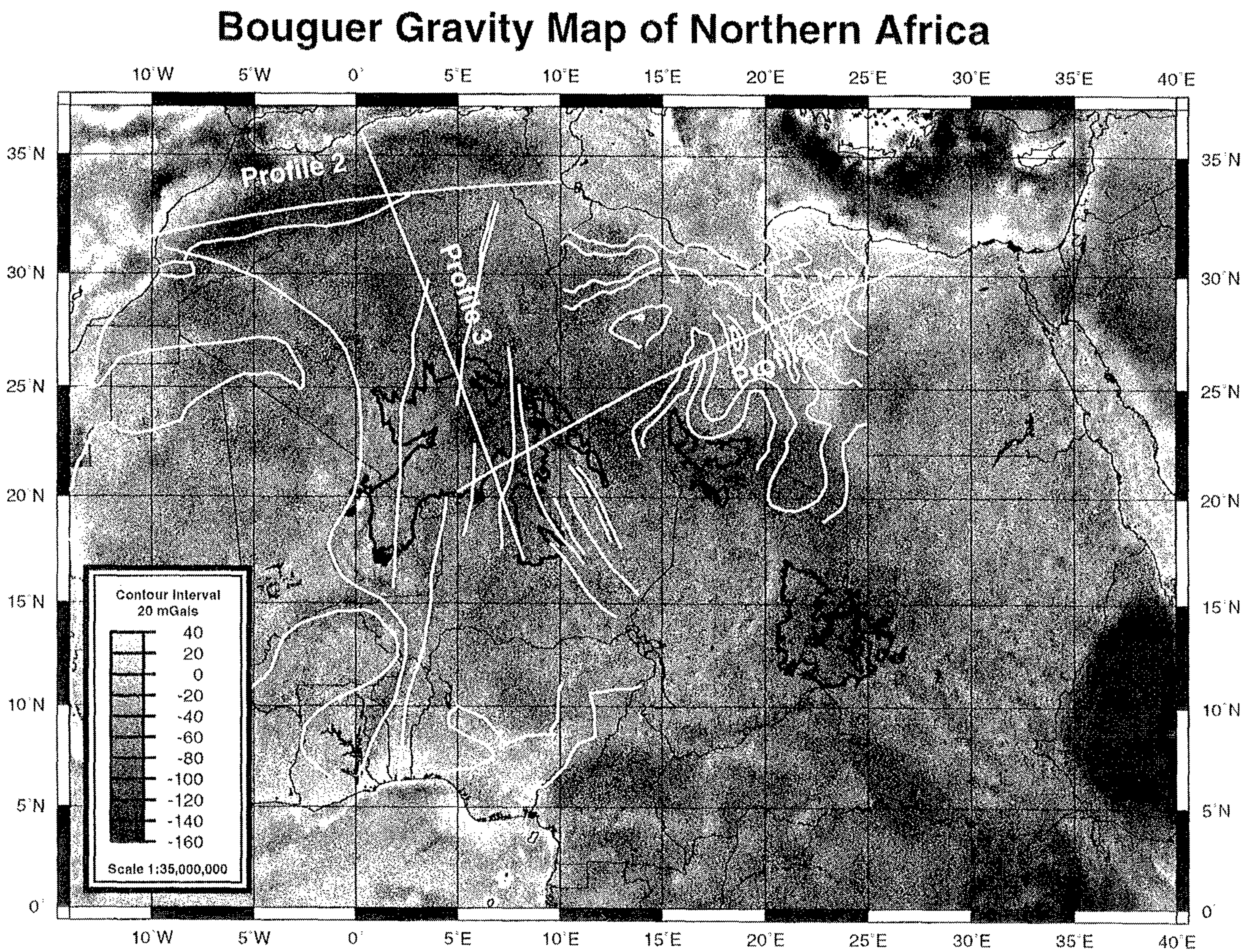

Figure A6. Structure of Precambrian in Libya, structure of West Africa

Appendix B - Documentation of Gravity Data Base

Two gravity data bases have been compiled for public use in North Africa. The first of these in the Defense Mapping Agency (DMA) data base that includes 36,410 gravity points distributed over North Africa north of 10 degrees north. These data include principal facts and are in the following format: field #1 - latitude in decimal degrees, field #2 - longitude in decimal degrees, field #3 - Bouguer anomaly in milligals using a 2.67 g/cc reduction density, field #4 - inner zone terrain correction, Hammer zones (A-F), in milligals, field #5 - outer zone terrain correction, Hammer zones G and beyond, in milligals, field #6 - elevation above sea level in feet, field #7 - observed gravity in milligals, and field #8 - source number indicating the origin of the data point. A value of -99.99 milligals in the terrain correction fields means that the terrain correction for that point has not been made. This data base is available on the UTEP web page under "DMA gravity".

The second data base available is more detailed data for an area surrounding the Gulf of Sirt. Except for 92 points in this data set principal facts are not available for these data. This data set includes 5531 gravity points. The format is the same as for the DMA gravity data described above, except that only the first three fields of data are given. This data base is available on the UTEP web page under "Sirt gravity".

A third proprietary data base was used to prepare the maps in this report and those available on the UTEP web page. This data base contains 477,298 gravity points, including those virtually all of the data points in the two data sets mentioned above and has been gridded at 5 minute intervals. Neither the data points nor the gridded data are available to the public. Individuals with specific interest in these data should contact G. Randy Keller at UTEP.

Appendix C - Documentation of Seismic Data Base

We have collected earthquake listings from the bulletins of the International Seismological Centre and the U.S. Geological Survey's Earthquake Data Reports for earthquakes of $M \geq 5.0$ and associated aftershocks occurring between 1963 and 1988 within North Africa. These data have been organized into a data base using the PC based program EXCEL. We have chosen this format for two reasons. First, it allows our students the ability to work at home at odd hours to enter information in the data base. Second, the students can relatively easily make relational plots from the data base. Two diskettes containing the data base have been included with the draft of this report. Additional diskettes are available from us upon request. We eventually plan to load the data base onto our departmental main frame so that it can be accessed by users through the Internet.

Figure C1 shows an example of the main spread sheet we have created for all events of interest. The spread sheet contains information on the date, time, latitude (lat), longitude (lon), depth, magnitude (Ms, mb or other), and location. We also keep track of whether we have obtained listings for the earthquake and plan to add columns for focal mechanism information.

For each earthquake for which we have obtained a listing, we have created the spreadsheet shown in Figure C2. The first line of the spreadsheet contains header information on the earthquake itself. Then we list all stations within 20° of the earthquake and note the station distance, station time, P-wave arrival time, S-wave arrival time, and arrival time of other phases, if given. We also record the delay time (observed arrival time minus predicted time). Magnitude information (usually log A/T) is also noted, when available. We will add another column that will give information on whether we were able to obtain seismograms for a particular station and the status of the seismograms (e.g. digitized, processed, modeled) when they have been obtained.

DATE	TIME	LAT	LON	DEPTH	Ms	Mb	MAGNITUDE	LOCATION	*	LISTING
4/16/69	8:12:56	27.3	33.9	33.0			5.0	Egypt		x
4/17/69	8:01:04	27.5	33.8	42.0			4.8	Egypt		x
4/23/69	13:37:17	27.5	33.7	18.0			5.0	Egypt		x
9/2/72	14:53:38	31.3	16.0	6.0		5.1	5.3	Sidra		x
9/4/74	6:29:14	33.0	13.5	0.0		5.2	5.5	Sidra		x
12/19/76	21:21:52	33.0	13.9	10.0		4.5	4.5	Sidra		x
1/19/77	20:46:53	36.5	8.4	21.0		4.9	5.7	A'in Soltane		x
2/9/77	13:55:00	36.4	8.4	41.0		4.5	4.9	A'in Soltane		x
10/10/80	12:25:17	36.1	1.4	0.0	7.2	6.3	5.5	El Asnam		x
10/10/80	12:37:08	36.3	1.5	0.0		5.6		El Asnam		x
10/10/80	14:12:27	36.1	1.3	16.0		4.7	4.6	El Asnam		x
10/10/80	14:44:51	36.3	1.4	0.0		5.4	5.3	El Asnam		x
10/10/80	15:18:46	36.0	1.5	10.0		3.8	4.0	El Asnam		x
10/10/80	15:25:36	36.0	1.3	10.0		4.6	4.6	El Asnam		x
10/10/80	15:36:52	36.4	1.7	10.0		4.8	4.9	El Asnam		x
10/10/80	15:39:06	36.2	1.6	3.0	6	6	6.1	El Asnam		x
10/10/80	17:15:17	36.3	1.6	10.0		3.9	4.0	El Asnam		x
10/10/80	17:32:59	36.1	1.4	10.0	4.7	5.4	5.2	El Asnam		x
10/10/80	19:07:59	36.4	1.6	0.0	4.5	5.4	5.0	El Asnam		x
10/10/80	20:22:41	36.5	1.5	10.0		4.5	4.3	El Asnam		x
10/10/80	21:21:18	36.2	1.7	10.0		4.1	4.2	El Asnam		x
10/10/80	23:55:33	36.2	1.8	10.0	3.4	4.2	3.2	El Asnam		x
10/10/80	23:59:58	36.2	1.3	10.0	3.4	3.9	3.4	El Asnam		x
10/11/80	1:29:16	36.3	1.5	10.0		4.1	4.2	El Asnam		x
10/11/80	5:40:48	36.3	1.6	10.0	3.9	4.6	4.6	El Asnam		x
10/11/80	19:30						4.3	El Asnam		
10/11/80	21:26:13	36.4	1.5	10.0	3.4	4.6	4.7	El Asnam		x
10/12/80	0:36:49	36.3	1.6	10.0		3.9	4.2	El Asnam		x
10/12/80	4:02:15	36.3	1.5	0.0	3.4	4.2	4.2	El Asnam		x
10/13/80	6:37:36	36.3	1.5	2.0	5.2	5.2	5.0	El Asnam		x
10/13/80	14:33:37	36.3	1.6	0.0	3.4	5	4.6	El Asnam		x
10/13/80	20:26:41	36.0	1.4	10.0		3.9	4.0	El Asnam		x
10/14/80	1:07:39	36.3	1.4	10.0		4	4.1	El Asnam		x
10/14/80							4.5	Algeria		
10/14/80	17:34:55	36.3	1.6	0.0	4.3	5.1	5.0	El Asnam		x

Figure C1. Example of page from master event spreadsheet that contains information on all earthquakes we plan to study.

Egypt	3/24/69	11:54:14	27.47N	33.87E	16km	Mag=4.9		
Station	**Distance**	**Azimuth**	**P arrival**	**P delay**	**S arrival**	**S delay**	**PP arrival**	**PP delay**
HLW	361.38	318	11:55:05	-0.06	11:55:50	5		
JER	493.70	15	11:55:20	-2.5	11:55:20	4		
CIN	1246.49	336	11:56:57	0.1	11:58:56	-7		
KSA	730.55	15	11:55:56	3.5	11:57:20	11		
VAM	1283.19	317	11:56:57	-4.3	-	-		
KER	1475.55	56	11:57:26	1.5	-	-		
ATH	1501.13	323	11:57:28	0.4	-	-		
TAB	1652.35	42	11:57:46	0.5	12:00:36	-		
VLS	1715.73	317	11:57:50	-2.8	-	-	11:58:04	12
PLG	1722.41	329	11:57:57	3.4	-	-		
GRS	1762.44	38	11:57:58	-0.3	-	-		
JAN	1809.14	322	11:58:08	4.4	-	-		
BKR	1810.25	27	11:58:01	-2.7				
SHI	1839.16	78	11:58:07	-0.1	-	-		
KRV	1855.84	35	11:58:09	0	-	-		
TIF	1868.07	29	11:58:10	-0.3	12:01:12	-4		
TEH	1893.65	57	11:58:15	1.7	-	-		
TIR	2000.39	324	-	-	12:01:50	6		
BUC	2003.73	342	11:58:18	-7.6	-	-		
AAE	2103.80	165	11:58:40	3.7	-	-		
CMP	2124.93	341	11:58:39	0.2	-	-		
VRI	2137.16	345	11:58:42	2.4	-	-		
KIS	2212.78	350	11:58:46	-1.9	-	-		

Figure C2: Example of spreadsheet data for an aftershock of the 1969 northern Red Sea earthquake sequence.

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